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SIMULATION OF THE J-2 ENGINE GIMBAL BEARING

By K. E. Demorest and K. W. Wilks
   Propulsion and Vehicle Engineering Laboratory

NASA

George C. Marshall

Space Flight Center,

Huntsville, Alabama

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ABSTRACT

$16 15^{-8}$

A test apparatus, designed to simulate the operation of the J-2 engine gimbal system, was used to test the J-2 gimbal lubricant at atmospheric pressure, at 10^{-6} mm of Hg, and over a wide range of temperatures. The currently specified gimbal lubricant, Fabroid (a product of the Micromatic Hone Corporation) consists of woven glass and Teflon fibers bound together with a phenolic resin. The Fabroid lubricant provided a low and constant coefficient of friction both at atmospheric pressure and at 10^{-6} mm of Hg at loads to 25,000 psi as long as the ambient temperature remained constant. However, the coefficient of friction of Fabroid was shown to be temperature dependent, increasing sharply with reducing temperatures. Although no experimental evidence indicated any degradation, the lubricating characteristics of Fabroid under high bearing loads had a tendency to fray and shed fibrous material during use at the higher loads.

Author

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PROPULSION AND VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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SIMULATION OF THE J-2 ENGINE GIMBAL BEARING

SUMMARY

A series of tests was made on the gimbal lubricant selected for the
J-2 engine gimbal. These tests were made on a simulator using small ball-
socket bearings lubricated with Fabroid, a woven glass-Teflon cloth
bonded to the surface with a phenolic resin. The Fabroid lubricant
appeared to be suitable for high load gimbal operation providing both
low friction characteristics and good wear life. Tests made at pressures
760 mm of Hg and 10^{-6} mm of Hg indicated that the Fabroid was not adversely
affected by a vacuum environment. Tests made over temperature ranges from
180°C to -100°C indicated that the coefficient of friction increased with
decreasing temperature from 0.02 - 0.03 at 180°C to 0.16 - 0.25 at -100°C.

INTRODUCTION

Engines on the upper stages of the Saturn vehicles operate in environ-
ments ranging from those of the earth atmospheric pressure to the vacuum
of space. The gimbal lubricants for these engines must be capable of pro-
viding a low and constant coefficient of friction at high unit loads through
these pressure environments and over the temperature range to which the
gimbal will be exposed. In the Saturn V launch vehicle, both upper stages,
the S-II and the S-IVB, utilize the J-2 engine, which is manufactured by
Rocketdyne, a division of North American Aviation, Incorporated. The S-II
stage uses a cluster of five J-2 engines for propulsion, and the S-IVB uses
a single J-2 engine. The gimbal lubricant which has been specified by
Rocketdyne for the J-2 engine is Fabroid (a phenolic resin-bonded glass-
Teflon woven fabric manufactured by the Fabroid Division of the Micromatic
Hone Corporation). The J-2 engine gimbal uses a ball and socket design to
support the full engine thrust. The gimbal will receive thrust loads of
200,000 pounds (approximately 25,000 psi based on the projected load carrying
area of the gimbal). The operation temperature range is not defined yet
but is assumed to be from 50°C to -180°C (122°F to -290°F).

TEST APPARATUS

The test apparatus which was used for simulating the J-2 gimbal bearing is shown in FIG 1 and 2. The parameters of the engine gimbal which were simulated included the bearing unit load, oscillating motion, and bearing materials, as well as temperature and pressure variations. The bearing used in the simulator was a standard number 03-001-0500 ball socket-type bearing, manufactured by the Fabroid Division of the Micromatic Hone Corporation. This bearing, which was used as the model bearing, had approximately four percent of the projected bearing area of the J-2 engine gimbal bearing.

As shown in FIG 2, the bearing shaft was supported by four large roller bearings mounted in the simulator frame. Because of the distributed load, these bearings contributed a negligible amount to the frictional force as compared to the test bearing in the center of the shaft. The bearing load was applied to the test bearing through a load cell by a screw-actuated pressor foot. A one-half inch thick ceramic disc was positioned between the pressor foot and the load cell to prevent heat transfer between the bearing and the load cell. The bearing shaft was provided with two arms which were connected to a motor-driven eccentric by a connecting rod on which were mounted strain gages for measuring the frictional force. The arms provided a mechanical advantage of 14:1, and the eccentric provided a total angle of oscillation of 14 degrees during operation of the device. The oscillation speed was 0.7 cycle per second. Temperature control of the bearing, while operating at reduced pressures, was provided by heating or cooling the pressor foot. At atmospheric pressure, low temperatures were obtained by surrounding the bearing with a controlled flow of liquid nitrogen. The bearing temperatures were measured by a thermocouple installed between the bearing outer race and the pressor foot.

DISCUSSION

Wear Life Evaluation

The first tests were made to determine the effect of operating time on the coefficient of friction of the Fabroid lubricant at atmospheric pressure and at 10^{-6} mm of Hg. Figure 3 shows the results of these tests at 25,000 psi unit load. These data indicate that the coefficient of friction of Fabroid is unaffected substantially by reduced pressures or by operating times up to 120 minutes (5000 cycles). At the completion of these tests, it was noted that the Fabroid was frayed; as a result, sheared fibrous particles of glass and Teflon were extruded from the edges of the bearing. A photograph of one of these bearings is shown in FIG 4, and sectioned views of the same bearing are shown in FIG 5.

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Vacuum Evaluation

A second series of tests was made to determine the effect of temperature variation on Fabroid operating at 10^{-6} mm of Hg. The nominal bearing unit load was set at 25,000 psi; however, since the bearing load was preset mechanically before the test chamber was evacuated, changes in temperature tended to vary the applied load on the bearing due to thermal expansion and contraction of the bearing components. Results of these tests with varying load are shown in FIG 6. The large variation in friction appeared to be dependent on temperature; however, the second-order effects of the load variation could not be eliminated from the vacuum tests. Since the previous evaluation indicated that low ambient pressures had little or no effect on the frictional characteristics of Fabroid, subsequent tests were made at atmospheric pressure to maintain the load and to achieve lower temperatures.

Temperature Evaluation

The tests reported in this section were made at atmospheric pressure. To lower the bearing temperature to the range of -150°C, the lower half of the bearing was submerged in liquid nitrogen during operation. Temperature control was maintained by varying the flow rate of the liquid nitrogen. Tests were made at three different unit loads (12,000 psi, 15,000 psi, and 25,000 psi) through a temperature range of 100°C to -150°C. Data were taken during both increasing and decreasing temperature changes to determine the temperature lag between the inner and outer races. Then, the raw data were corrected by the known temperature lag to provide the curves shown in FIG 7. The results of tests made by Rocketdyne on a full scale J-2 gimbal are compared with the results obtained at 25,000 psi on the simulator. The data obtained from Rocketdyne indicate that a maximum coefficient of friction is reached at approximately -100°C. These results were not in agreement with those obtained at Marshall Space Flight Center (MSFC), where the coefficient of friction continued to increase with decreasing temperature. Greater confidence is placed in the MSFC data based on the information available. First, regarding experimental procedure, the bearings were cooled by immersion in liquid nitrogen, which necessitated a temperature lag between outer surface and actual bearing surface. This lag was measured and compensated in the MSFC data taken on the small mass of the model bearing. A much greater temperature lag should have been observed in the Rocketdyne test because of the larger bearing mass. The Rocketdyne data presented in FIG 8 could be explained better if they were based on the coefficient of friction of the internal bearing surface corresponding to temperature measurements on the colder outer surface. Secondly, regarding the material properties, the increase in friction with decreasing temperature is believed to be based on the increase in modulus (stiffness, hardness, or shear resistance) of Teflon. The modulus of Teflon increases 35 percent from -100°C to 180°C (ref. 1). The MSFC data indicate a 50 percent increase in friction over the same temperature range, whereas Rocketdyne data indicate that the friction is constant.

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CONCLUSIONS

The results of this program indicate clearly the necessity for a careful temperature analysis of the J-2 engine gimbal bearing when incorporated into the Saturn upper stages. Until such an analysis is completed, one cannot recommend Fabroid for the bearing lubricant unless the hydraulic actuation system of the J-2 engine can be designed to accommodate the wide variation in gimbal friction which has been demonstrated to occur as a function of temperature. If the temperature profile of the bearing in stage application is such that the lubricating characteristics of Fabroid are unsatisfactory, currently available dry film lubricants, which are essentially insensitive to temperature and are effective at high loads, such as those used on the Centaur stage engine gimbal bearing, could be substituted for the Fabroid but would require a redesign of the gimbal bearing to accommodate changes in lubricant thickness.

Specific conclusions which can be drawn from the evaluation program are listed below:

1. The Fabroid gimbal lubricant provides a low and constant coefficient of friction, at atmospheric pressure and at 10^{-6} mm of Hg, when exposed to unit loads of up to 25,000 psi if the temperature remains relatively constant at 25°C and the number of operating cycles does not exceed 5,000.

2. The lubricant tends to wear and shed fibers of glass and Teflon during long periods of operation at high loads; however, no increase in friction was noted as a result of this during the duration of the testing cycle.

3. The coefficient of friction of Fabroid increases sharply with decreasing temperature, changing from approximately 0.04 at +100°C to 0.22 at -180°C.

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REFERENCES

1. McKannan, E. C.; and Gause, R. L.: Effects of Nuclear Radiation and Cryogenic Temperatures on Engineering Materials. NASA TM X-53152, October 22, 1964.

2. Rocketdyne Letter 64RC20871, "J-2 Gimbal Bearing Coefficient of Friction and Friction Moment Equations," January 6, 1965.
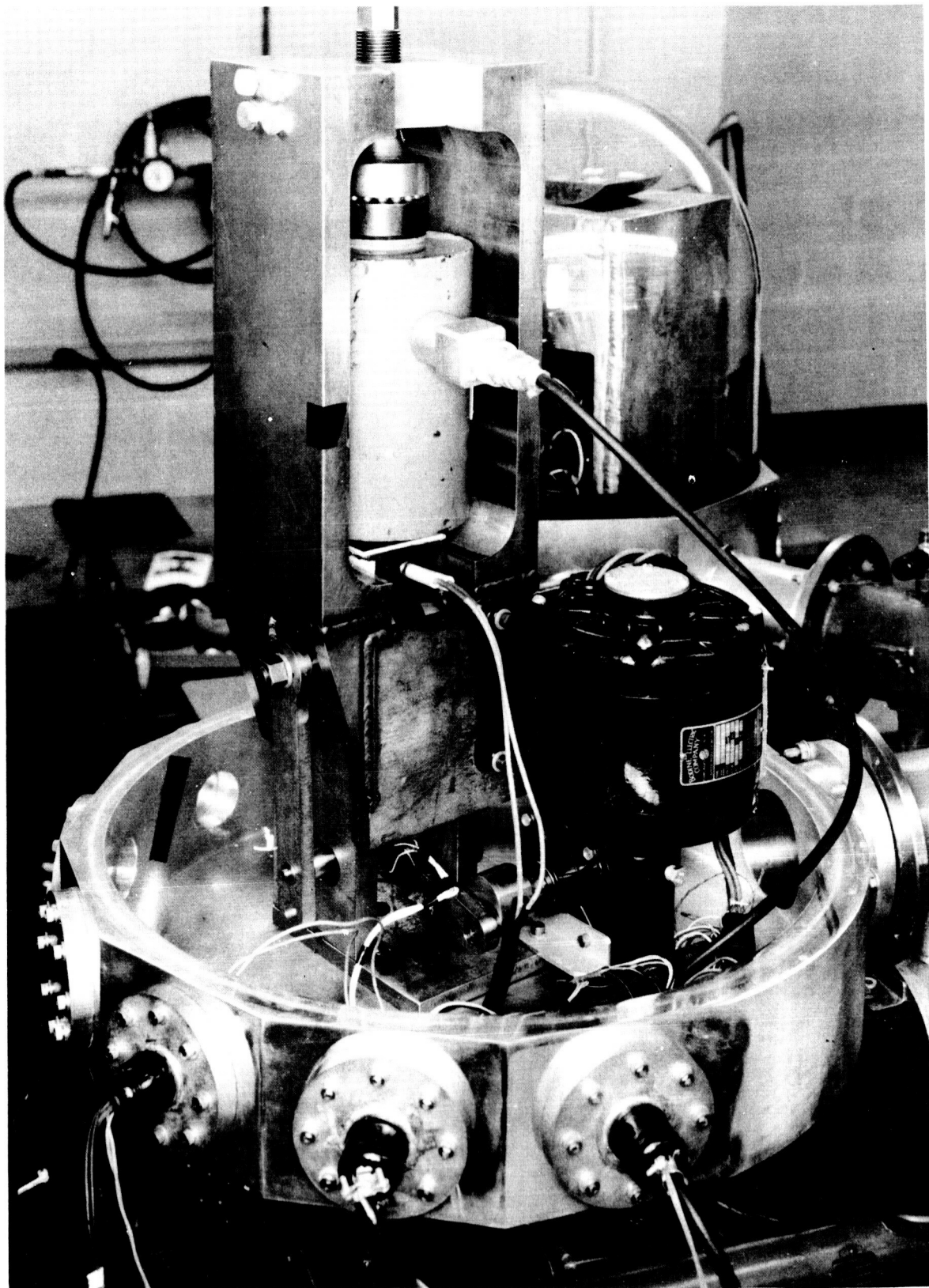
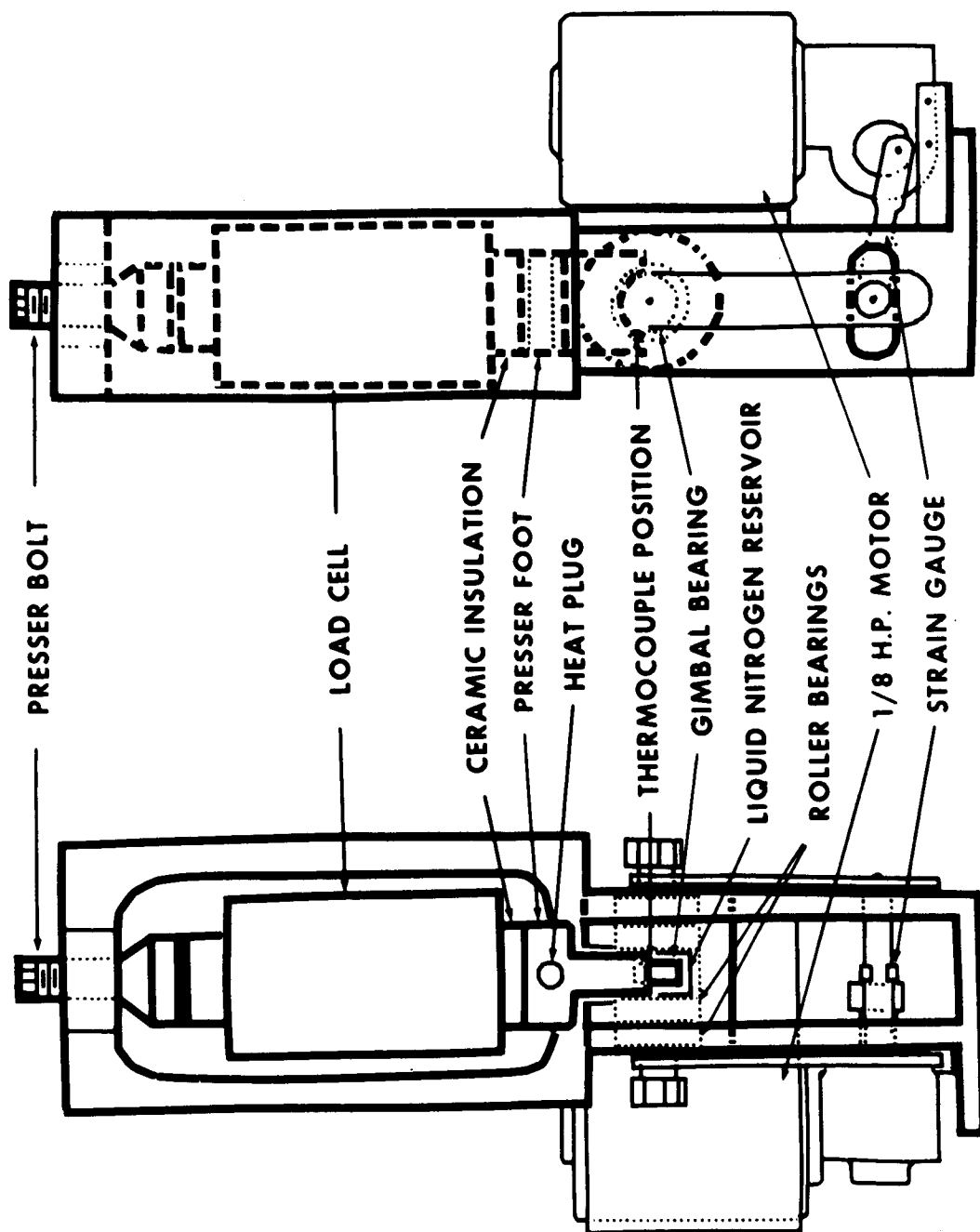**FIGURE 1.- PHOTOGRAPH OF HIGH LOAD GIMBAL TESTER**

PRESSER BOLT

LOAD CELL

CERAMIC INSULATION

PRESSER FOOT

HEAT PLUG

THERMOCOUPLE POSITION

GIMBAL BEARING

LIQUID NITROGEN RESERVOIR

ROLLER BEARINGS

1/8 H.P. MOTOR

STRAIN GAUGE

FIGURE 2. - SCHEMATIC OF HIGH LOAD GIMBAL TESTER

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FIGURE 3.- COEFFICIENT OF FRICTION
VS OPERATING TIME

EXTRUDED GLASS AND TEFLON FIBER

0   INCH   1
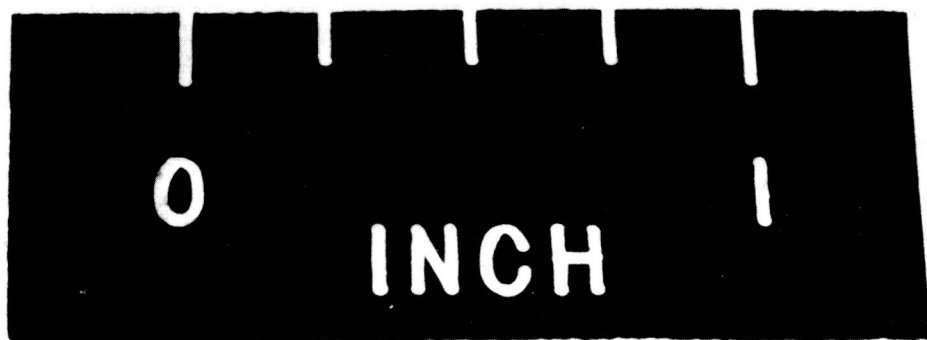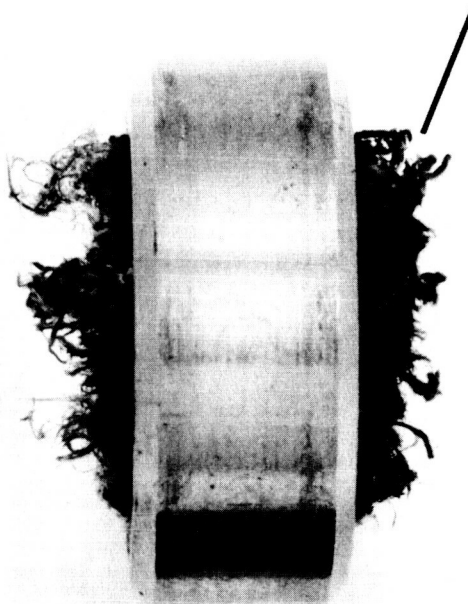
FIGURE 4.- WEAR ON FABROID LUBRICATED BEARING
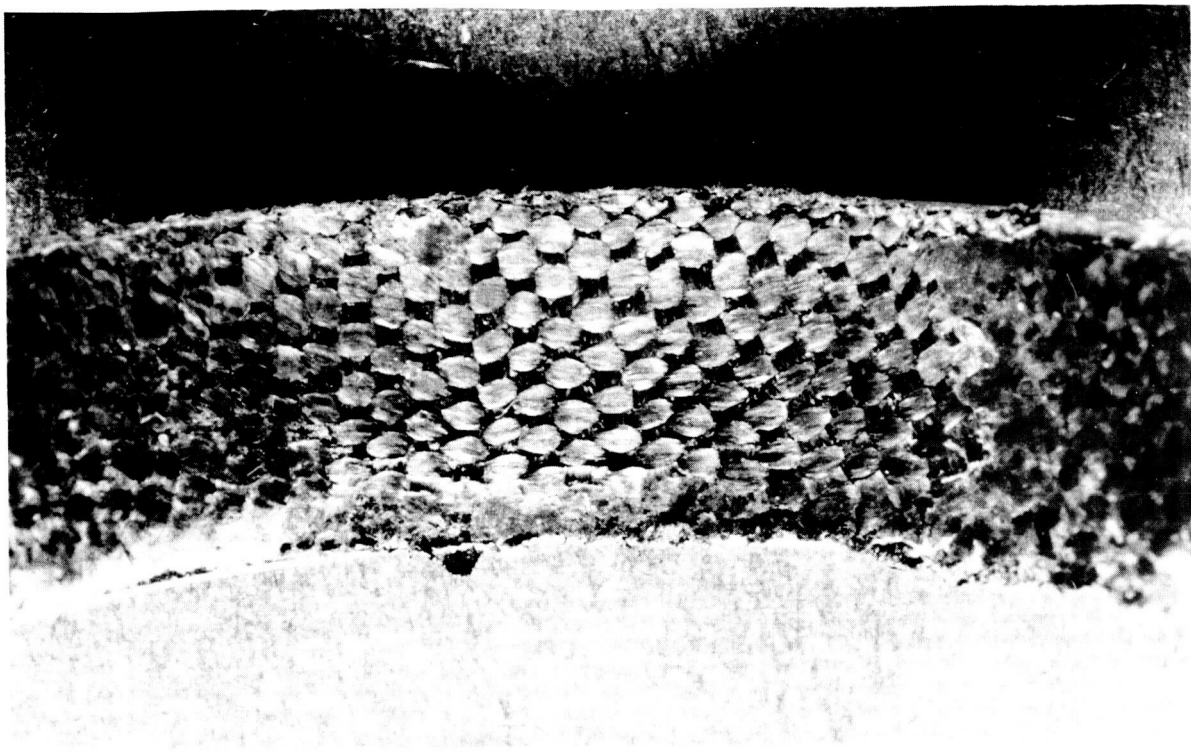
UNLOADED SECTION
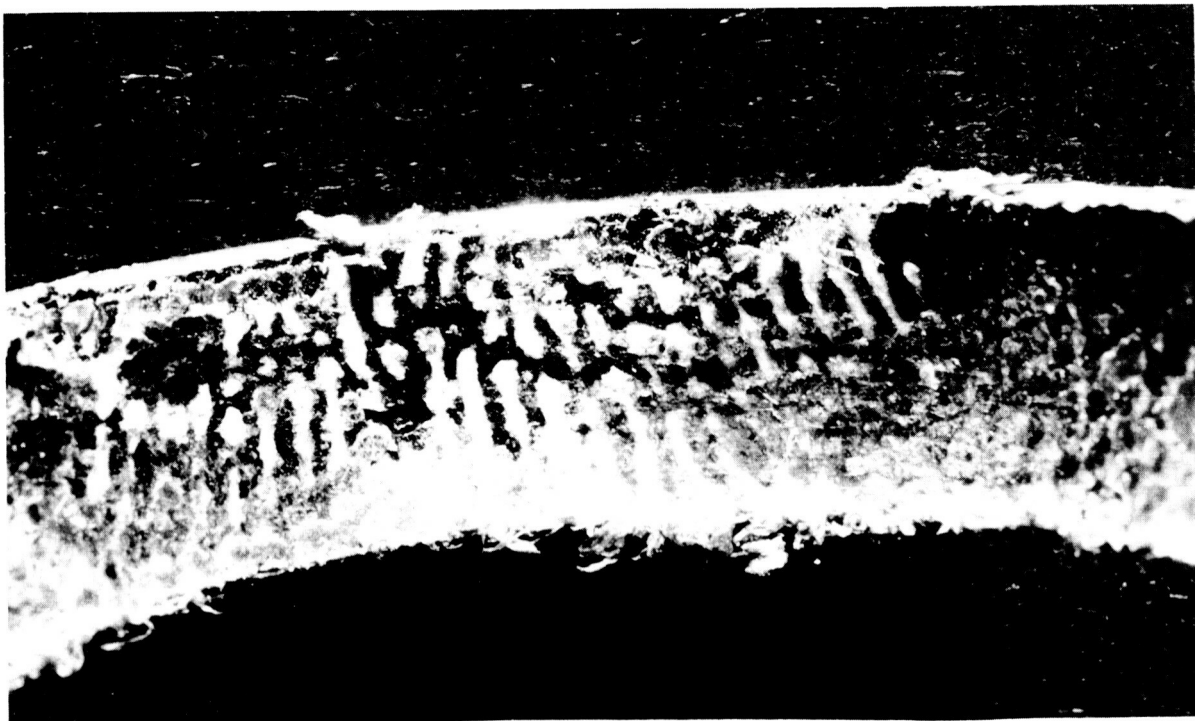
LOADED SECTION

FIGURE 5.- FABROID BEARING SECTIONS

PRESSURE   3 x 10^{-6} MM HG

18,000 psi

25,000 psi

30,000 psi

COEFFICIENT OF FRICTION

.16

.12

.08

.04

TEMPERATURE, °C

-100   -60   -20   20   60   100   140   180
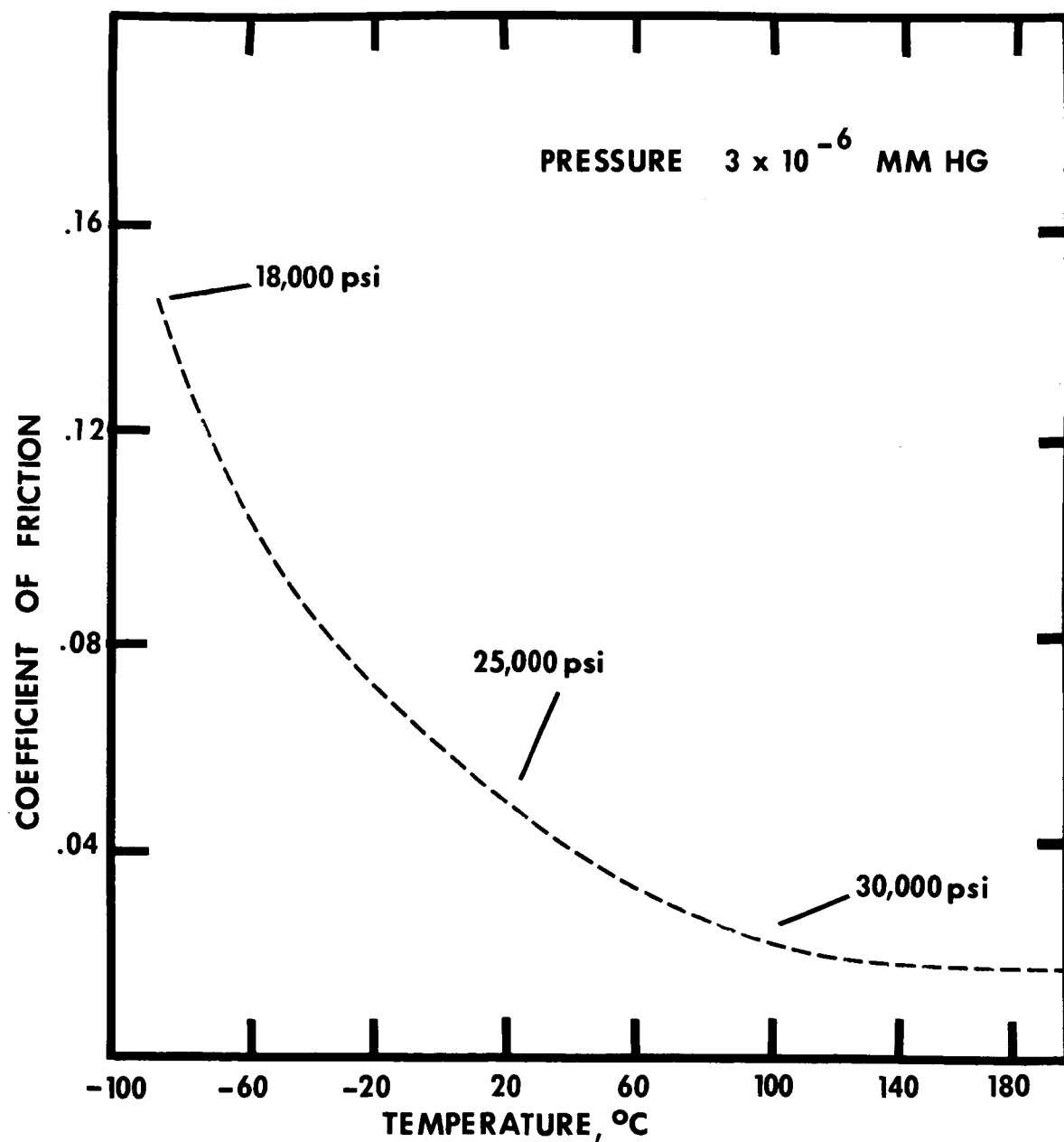
**FIGURE 6.-COEFFICIENT OF FRICTION
VS TEMPERATURE**

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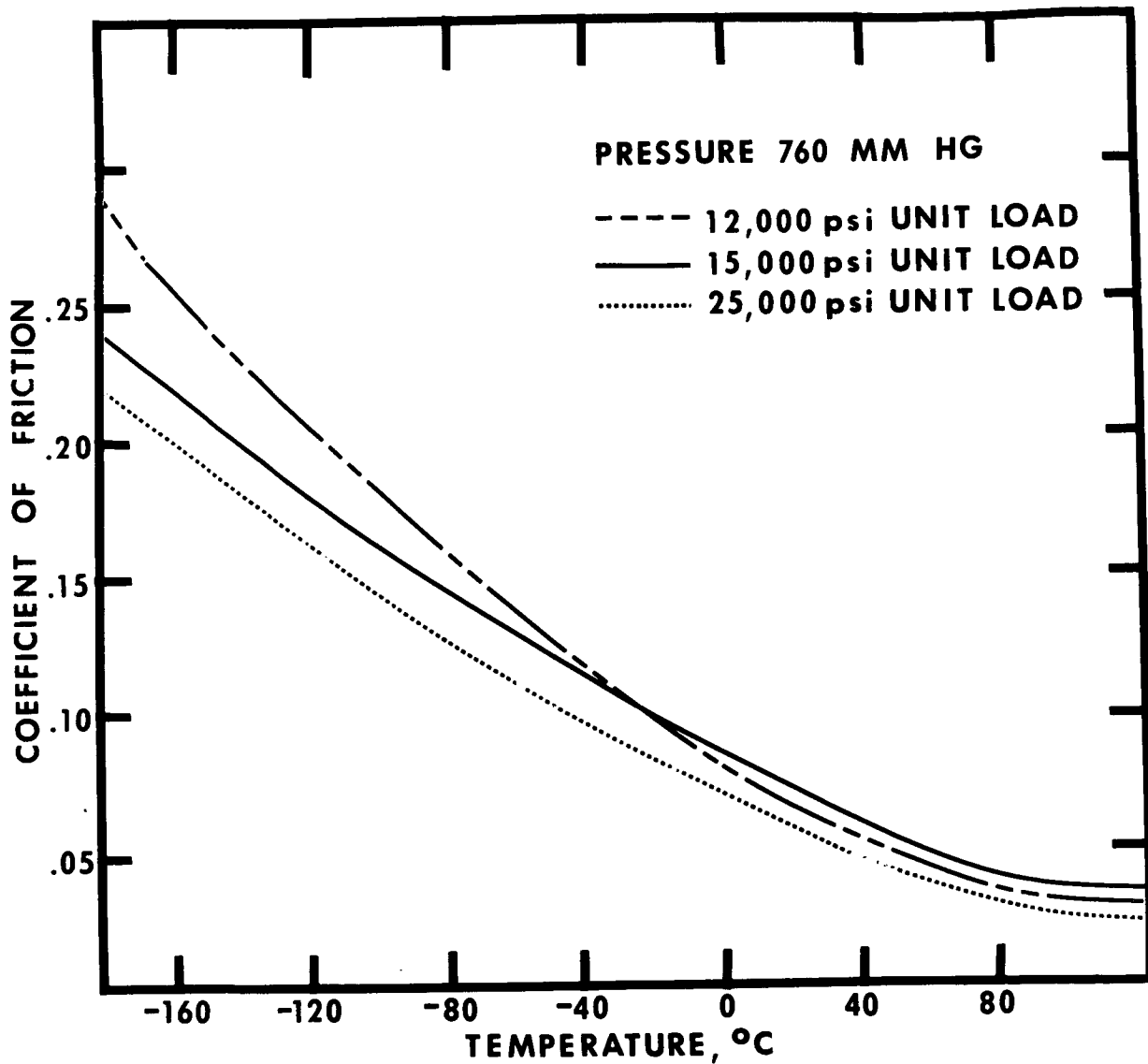
FIGURE 7.-COEFFICIENT OF FRICTION VS
TEMPERATURE AT THREE LOADS
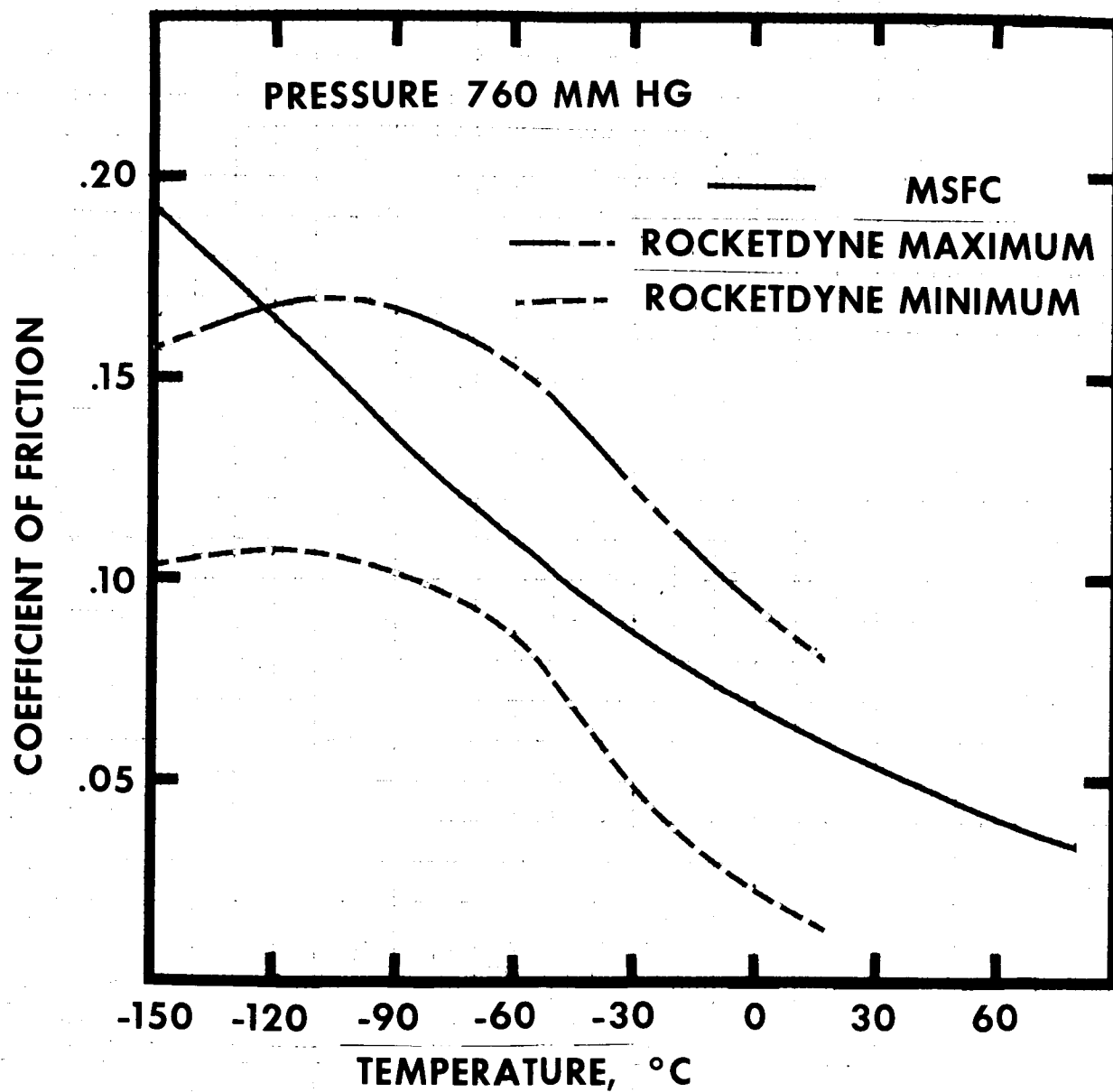
FIGURE 8. COEFFICIENT OF FRICTION VS
TEMPERATURE AT 25,000 PSI
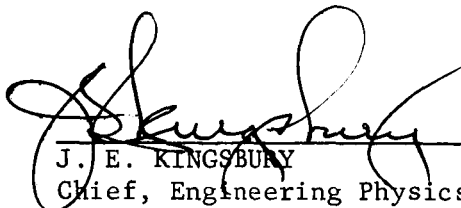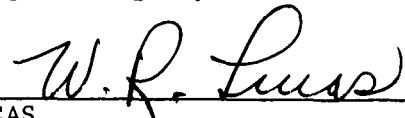
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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

J. E. KINGSBURY
Chief, Engineering Physics Branch

W. R. LUCAS
Chief, Materials Division

F. B. CLINE
Director, Propulsion and Vehicle Engineering Laboratory